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There is general concern that atmospheric pollutants may be affecting the health of forests in the United States (Barnard 1986). In response to that concern, we began a program of research in 1985 on the relations between forest condition and atmospheric deposition across the Great Lakes region. Because widespread forest damage or decline is not visible in this region, the research was aimed at detecting subtle regional trends related to acidic deposition in general and to sulfate deposition in particular. The hypotheses tested were that the wet sulfate deposition gradient across the Lake States is (Harris and Verry 1985; Verry and Harris 1988): (1) reflected in the amount of accumulated sulfur in the forest floor-soil system and tree woody tissue and (2) related to differences in tree radial increment. We also hypothesized that these relations can be distinguished from those related to site and climatic variation across the region (Ohmann *et al.* 1987, 1988; Holdaway 1989; Shifley 1988; David *et al.* 1988; Grigal and Ohmann 1989; Ohmann and Grigal 1990).

Study plots were established across the acidic deposition gradient to test the general hypotheses. Earlier NC Resource Bulletins (Ohmann *et al.* 1989; Ohmann and Grigal 1991) detailed the physical characteristics and chemical properties of soils and tree wood tissue of those plots, including particle-size analyses of soils and the chemical properties of the soil and tree wood tissue by zone and forest type. In this Bulletin, we present the vegetative characteristics of the five forest types inventoried on the study plots. Knowledge of the vegetative characteristics of the forest types studied is useful in understanding and interpreting relations between sulfate deposition, sulfur accumulation in the ecosystem, soil and tree chemistry, and tree growth and climatic variation. Data in this and the earlier Bulletins (Ohmann *et al.* 1989, Ohmann and Grigal 1991) may be useful for study, analysis, and interpretation.

METHODS

Plot Selection

The data were collected across the forested portions of Minnesota, Wisconsin, and Michigan. Plot selection has been documented in detail (David *et al.* 1988; Grigal and Ohmann 1989). Briefly, a stratified random sample of 171 USDA Forest Service inventory plots within the three States was selected (fig. 1). Stratification was intended to balance the plots geographically among five zones running roughly northwest to southeast across the three States, and among five forest types: balsam fir (n=26) (see table 33 for scientific names of species), northern hardwoods dominated by sugar maple (n=41), jack pine (n=39), red pine (n=27), and aspen (n=38). To control the effects of growth variation due to natural biological factors, we limited sampling to a narrow range of initial ages, site indices, and densities while maintaining approximately eight plots per forest type per geographic zone (table 1). Plots were randomly selected within each type by geographic zone and age-site-density class. Although 171 plots were sampled, two balsam fir plots were dropped from most of the analyses because high organic content

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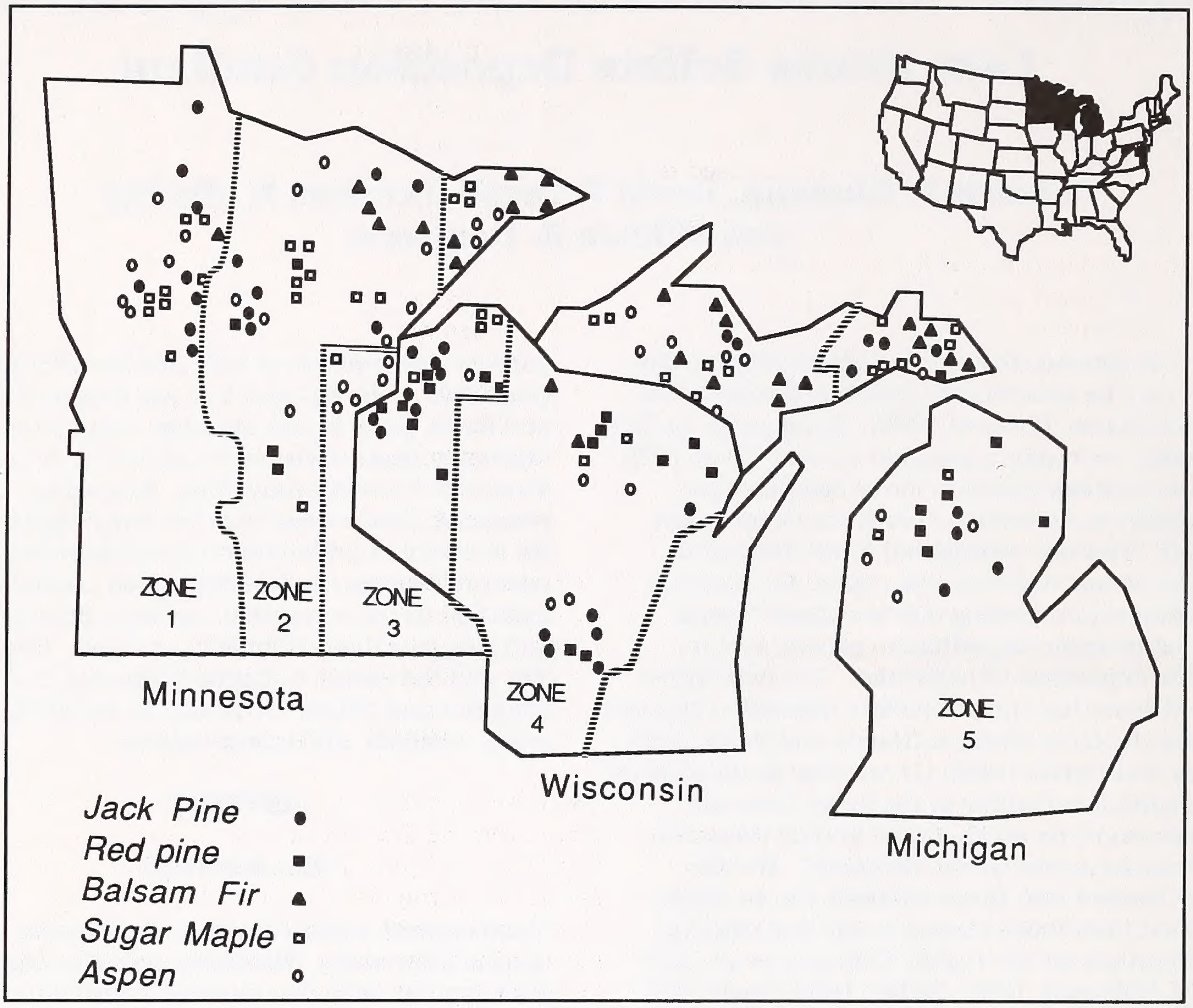

Figure 1.—Distribution of plots sampled along an acid sulfate deposition gradient across the Lake States.

of the soils indicated that they did not meet the plot selection criteria of being located on well-drained upland mineral soil. In most cases, data from those two plots were outliers and are not included in this Bulletin. Most of the red pine stands are plantations; stands of the other forest types are naturally established. The sampled plots occur on a variety of landforms; about one-fourth are on soil mapping units dominated by Alfisols, one-fourth on Entisols, one-fourth on Spodosols, one-sixth on Inceptisols, and one-tenth on other soil orders or on unmapped soils (Ohmann *et al.* 1989). Precipitation and temperature differ significantly among geographic zones, ranging from 64 cm annual precipitation and 3.8 ^{o}C mean annual temperature in zone 1 (farthest northwest) to 81 cm and 5.8 ^{o}C in zone 5 (farthest southeast).

Field Sampling

Field measurements on the inventory plots were taken from June through October 1985, following standard Forest Inventory and Analysis procedures for the Lake States (Doman *et al.* 1981). Forest Service inventory plots are clusters of 10 subplots arranged in roughly an elliptic configuration, with measured (tally) trees selected with a probability proportional to their size (Doman *et al.* 1981). Total area of the 10 subplots is about 0.4 ha. At the center of each subplot, we sampled trees 12.7 cm d.b.h. and larger, using an 8.6 m^2 ha^{-1} basal-area-factor prism. At the first three subplots, trees between 2.5 and 12.6 cm d.b.h. were sampled on circular 13.5 m^2 plots. Species and d.b.h. were recorded for each tree; 6,602 trees were measured.

Numerical Analyses

Presence

Within each forest type, the number of inventory plots on which a species was recorded was used to calculate a percent presence for each species. Relative Presence, the percent of total presence contributed by each species for a type, was also calculated and used to produce an importance value for each species.

Density

Density, the number per hectare of woody stems 2.5 cm and larger, was calculated for each species from the number of trees of each species recorded in the prism and circular sample plots. Species densities were averaged over all plots for each forest type. Relative Density, the percent of total stems contributed by each species for a type, was also calculated and used to produce an importance value for each species.

Basal Area

Species basal area was estimated from measurements of breast height diameter recorded for each tree on the prism and circular sample plots. Estimates for each species were averaged over all plots for each forest type.

Biomass

Aboveground biomass and biomass of large roots of each tree were estimated from previously published estimation equations that use d.b.h. as the independent variable. The broad generality of such equations has been demonstrated repeatedly (Grigal and Kernik 1984, Schmitt and Grigal 1981). Equations included those used by Ohmann and Grigal (1985), with modifications for additional species and with recent equations based on more observations. For uncommon and unidentified species, general equations from Clark *et al.* (1986) were used. The all-hardwoods equation was used for unidentified hardwood species, and the hard hardwoods equation was used for uncommon high-density hardwoods such as American hornbeam and ironwood. Equations for other species were either the only existing equation for that species or, when many equations were available, the one that provided a median biomass estimate (Grigal and Ohmann 1992).

Equations to estimate root biomass are rare; a general equation for larger roots of woody species developed by Whittaker and Marks (1975) was used for nearly all species. Fine roots, those less than about 5 mm in diameter, constitute about 5 percent of the total root mass (Keyes and Grier 1981); ignoring them has minor effects on the overall biomass estimate.

Total aboveground and belowground biomass for each species was averaged over all plots for each forest type. Relative Dominance (biomass), the percent of total biomass contributed by each species for a type, was also calculated and used to produce an importance value for each species.

Importance Value (IV)

The relative values of presence, density, and dominance (biomass) were combined as an overall importance value (IV) by averaging them for each species within each forest type.

RESULTS AND DISCUSSION

The number of tree species recorded in the inventory of the five forest types differs; the conifer types (jack pine, red pine, and balsam fir) have fewer species than the broadleaf forest types (sugar maple and aspen) (table 2). Some species were recorded in only one type: black oak in the xeric jack pine type, the exotic scotch pine in some of the red pine plantations, bitternut hickory in the sugar maple type, and chokecherry, American hornbeam and sassafras in the aspen forest type. American basswood, hemlock, and green ash were recorded only in the two broadleaf (sugar maple and aspen) forest types, and northern pin oak was recorded only in the two conifer (jack pine and red pine) forest types. Some species were represented in all forest types, but at different levels of biomass accumulation and importance value. These include quaking aspen, northern red oak, paper birch, bigtooth aspen, white pine, white spruce and sugar maple (table 2).

Mean tree density for the conifer forest types is generally lower than that for the hardwood forest types (table 3), but there is no similar trend for basal area or biomass. There is a trend of lower values for all vegetative characteristics from northwest (zone 1) to southeast (zone 5) across the gradient within the jack pine and sugar maple forest types (table 3). Shifley (1988), in a detailed

analysis of individual tree growth patterns of jack pine, red pine, balsam fir, sugar maple and aspen trees between 13 and 23 cm d.b.h, found differences in four of the five species that might be associated with increases in sulfate deposition across the geographic zones from northwest to southeast. However, the trend was one of increased growth for sugar maple and aspen and decreased growth for jack pine and red pine.

Although the red pine forest type has the largest mean basal area, the sugar maple forest type represents the largest tree biomass (table 3), probably due to a higher wood density.

Jack Pine Forest Type

Jack pine strongly dominates the plots inventoried as jack pine forest type, as indicated by its IV and the other vegetative characteristic values (table 4). Seventeen woody species were recorded in the sample plots within the jack pine forest type; but other than jack pine, no species were recorded in more than half of the 39 stands inventoried, and only quaking aspen, bur oak, red pine, and northern red oak had IVs of 5 percent or greater (table 4).

Jack pine is more important in the jack pine forest type in zones 3, 4, and 5 (61, 59, and 67 percent IV, respectively) where the sites are probably a bit more xeric (sandy and drier) as indicated by the presence of black oak and pin oak (tables 5 through 9). Although quaking aspen was recorded in the jack pine type plots in all five zones, it is most important as an associate species in zones 1 and 2 (tables 5 and 6). Ten and nine species were recorded in zones 1 and 2 respectively. Among them are balsam fir, tamarack, white spruce, sugar maple, and mountain maple, indicating that the inventory plots in those two zones are probably more mesic. Zones 3 through 5 contained 5, 11, and 7 species, respectively, including more oaks and red pine and white pine (tables 7 through 9).

Red Pine Forest Type

Red pine is the most important species within the red pine forest type (table 10) with an IV of 64 percent and about 80 percent of the estimated biomass. Eighteen species were recorded in the inventory of the type. Other than red pine, only quaking aspen and jack pine IV averaged more than 5 percent. The presence of the exotic scotch pine is a reflection of the plantation origin of many of the red pine stands, which were included in the inventory because few stands of natural origin exist in the region.

No FIA plots in the red pine forest type met the study criteria in geographic zone 1. Red pine was somewhat more important in the red pine forest type in zones 3 and 4 than in zones 2 and 5 (tables 11 through 14). In zone 2 the difference is likely due to the presence of scotch pine (10 percent IV) that was planted along with the red pine. In zone 5 some of the plots inventoried were stands comprised of a red pine and jack pine mixture (jack pine IV of 11 percent). The number of species recorded in the inventoried plots was fairly constant across the four zones (8, 6, 8, and 10, respectively). The presence of sugar maple, white ash, American elm, and black cherry suggests that one or more of the plots in zones 4 and 5 were of non-plantation origin or were more mesic than would be typical of the red pine forest type (tables 13 and 14).

Balsam Fir Forest Type

In contrast to the jack pine and red pine forest types, balsam fir does not strongly dominate the forest type (table 15). Balsam fir has a mean IV of 31 percent. Twenty species were recorded in the sample plots within the forest type. Paper birch is a major associate species (mean importance value of 19 percent) and was present in 20 of the 24 plots inventoried. Other important associated species are white spruce, northern white-cedar, quaking aspen, and red maple. Although balsam fir does not strongly dominate its type as do jack pine and red pine in those forest types, the total biomass represented for the type is as high as that for the red pine type and higher than that of the jack pine type (table 15), probably because of the greater number of species contributing to the total.

Only one plot of the balsam fir forest type met study criteria in zone 1 (table 16), thus the values for that zone may not be representative of the type. Balsam fir was the most important species in all zones other than zone 1 (tables 17 through 20), but the contribution to density, basal area, and biomass by other species such as paper birch,

quaking aspen, and red maple was also high (tables 17 through 20). The balsam fir forest type represents a more mesic condition than the previous two conifer types, as is evidenced by the presence of ash and elm that were recorded in at least some of the plots and the absence of bur oak, northern pin oak, and black oak that are characteristic of the more xeric pine types.

Sugar Maple Forest Type

Sugar maple does not dominate the northern hardwoods forest type (38 percent IV) (table 21) to the extent that jack pine and red pine dominate their forest types. Twenty-five species contributed to stand composition and vegetative characteristics (table 21). American basswood, red maple, yellow birch, beech, and black cherry are all important associate species in the sugar maple forest type; it is technically a northern hardwoods type (table 21). Some typical northern hardwoods associates do not occur within the type across all five geographic zones; for example, beech and hemlock are not present in zone 1 and parts of zone 2 and 3.

Sugar maple is a more important component of the forest type (tables 22 through 26) in zones 4 and 5 (47 and 48 percent IV and 82 T ha^{-1} biomass) than in zones 1 through 3 (26, 35, and 36 percent IV and 49, 59, and 59 T ha^{-1} biomass, respectively). A part of that difference may be due to the greater importance of American basswood in the plots inventoried in zones 1 and 2 (tables 22 and 23) and of northern red oak in zone 3 (table 24). Part of the difference may also be due to the greater species diversity; 14, 18, and 16 species in zones 1 through 3, and 16 and 12 species in zones 4 and 5 (tables 22 through 26). Species composition, however, does not explain the difference in biomass estimates for sugar maple, which are 23 to 33 T ha^{-1} higher in zones 4 and 5. Basal areas are also higher in zones 4 and 5, and probably reflect greater stand ages rather than increased sugar maple productivity associated with higher temperature and moisture in the southeast portion of the gradient. Mean total biomass, which is very similar across the five zones (table 2), also suggests that the difference is due to stand age rather than stand productivity.

Aspen Forest Type

Aspen, like sugar maple and balsam fir, does not strongly dominate its forest type (IV = 36%) (table 27). More species were recorded in the inventoried plots of the aspen forest type (27) than in any of the others studied (table 27). The most important associates are paper birch, red maple, and balsam fir.

More species were recorded in the aspen type in zones 4 and 5 (18 and 19 species, respectively) than in zones 1 through 3 (10, 14, and 15 species, respectively) (tables 28 through 32). Red maple and balsam fir appear to be more important associates in zones 4 and 5, and paper birch is more important in zones 2 and 3 (tables 28 through 32).

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DEFINITIONS OF TERMS USED IN TABLES

Number of plots = number of forest type plots in which a species occurred across five sampling zones from northwestern Minnesota to southeastern Michigan.

Density = number of woody stems 2.5 cm or larger in diameter at breast height averaged over all plots.

Basal area = basal area calculated from measured diameter of woody stems 2.5 cm or larger d.b.h. averaged over all plots.

Biomass = estimated aboveground and belowground biomass of woody stems 2.5 cm or larger d.b.h. averaged over all plots. Reported in metric tons (T).

Importance value = relative presence (number of plot occurrences), relative density, and relative biomass expressed as a percent and averaged over all plots.

Table 1.—*Condition of plots before 1985 inventory. Values are based on last previous inventory. Maximum and minimum indicated.*

Forest type	Plots	Basal area	Site index	Stand age
	Number	*m^2ha^{-1}*	*m at age 5*	*Years*
Jack pine	39	15 - 24	14 - 20	35 - 55
Red pine	27	13 - 30	17 - 23	17 - 45
Balsam fir	26	17 - 31	13 - 18	45 - 65
Sugar maple	41	19 - 35	13 - 22	45 - 65
Aspen	38	14 - 25	18 - 23	35 - 49

Table 2.—*Species biomass by forest type across five sampling zones from northwestern Minnesota to southeastern Michigan*

Species	Forest type				
	Jack pine	Red pine	Balsam fir	Sugar maple	Aspen
	$T\ ha^{-1}$				
Jack pine	63.9	4.5	0.9	—	0.2
Quaking aspen	6.5	3.7	12.3	7.2	59.2
Bur oak	1.9	<0.1	—	2.5	3.0
Red pine	3.9	86.7	10.3	—	0.6
Northern red oak	3.3	0.7	1.1	14.2	3.1
Paper birch	1.9	0.7	25.4	7.2	6.7
Black oak	2.6	—	—	—	—
Bigtooth aspen	1.3	0.7	0.1	3.5	4.6
Black spruce	0.3	—	3.1	—	0.3
White pine	0.1	1.5	1.9	0.1	<0.1
White oak	0.3	—	—	—	0.6
Northern pin oak	0.7	0.9	—	—	—
Balsam fir	0.3	—	34.9	1.8	6.4
Tamarack	<0.1	—	1.2	<0.1	—
White spruce	0.6	2.5	4.1	0.4	1.8
Sugar maple	0.1	1.4	0.5	66.3	3.1
Mountain maple	<0.1	—	0.9	<0.1	—
Red maple	—	1.3	4.2	10.0	11.8
Black cherry	—	0.5	—	2.0	0.8
Scotch pine	—	2.1	—	—	—
White ash	—	1.4	—	4.3	—
Balsam poplar	—	0.2	1.5	<.1	2.6
American elm	—	0.8	0.7	6.0	3.4
Northern white-cedar	—	—	4.9	0.3	0.6
Yellow birch	—	—	2.0	3.7	0.9
Black ash	—	—	0.2	1.1	0.4
Eastern hophornbeam	—	—	0.2	3.3	0.6
American basswood	—	—	—	12.3	1.6
Hemlock	—	—	—	0.9	0.3
Green ash	—	—	—	0.7	0.1
Beech	—	—	—	1.6	—
Bitternut hickory	—	—	—	0.2	—
Chokecherry	—	—	—	—	<0.1
American hornbeam	—	—	—	—	<0.1
Sassafras	—	—	—	—	<0.1
Unidentified	—	0.6	<0.1	0.7	<0.1
Total biomass	87.7	110.2	110.4	150.3	113.7
Total species	17	17	20	25	27

Table 3.—*Forest type vegetative characteristics in each of five sampling zones from northwestern Minnesota to southeastern Michigan*

Forest type	Zone 1	2	3	4	5	Mean
	Density (stems ha^{-1})					
Jack pine	1,208	1,651	1,128	1,066	987	1,208
Red pine	—	1,709	1,626	1,092	1,266	1,423
Balsam fir	702	1,396	1,651	1,389	1,654	1,358
Sugar maple	2,024	1,447	1,930	1,479	1,165	1,609
Aspen	1,316	1,395	1,980	1,933	1,591	1,643
Mean	1,312	1,520	1,663	1,392	1,333	
	Basal area (m^2ha^{-1})					
Jack pine	24	23	17	16	20	20
Red pine	—	31	26	25	28	28
Balsam fir	23	29	27	23	29	26
Sugar maple	28	26	25	25	25	26
Aspen	23	23	24	23	25	24
Mean	24	26	24	22	25	
	Biomass (T ha^{-1})					
Jack pine	108.3	102.5	69.6	72.2	86.3	87.8
Red pine	—	123.6	99.6	102.4	114.5	110.0
Balsam fir	128.0	112.1	105.6	96.7	110.2	110.5
Sugar maple	160.7	157.9	141.1	142.2	151.2	150.6
Aspen	107.4	109.9	111.6	114.7	121.6	113.0
Mean	126.1	121.2	105.5	105.6	116.8	

Table 4.—*Jack pine forest type species composition and vegetative characteristics, all sampling zones*

Species	Plots	Density	Basal area	Biomass	Importance value
	Number	*Stems ha^{-1}*	*m^{2}ha^{-1}*	*T ha^{-1}*	*Percent*
Jack pine	39	745	15.1	63.9	57
Quaking aspen	15	171	1.6	6.5	11
Bur oak	12	105	0.5	1.9	7
Red pine	10	35	0.8	3.9	5
Northern red oak	9	48	0.6	3.3	5
Paper birch	6	22	0.3	1.9	3
Black oak	4	25	0.4	2.6	3
Bigtooth aspen	3	14	0.3	1.3	2
Black spruce	2	10	0.1	0.3	1
White pine	2	1	0.0	0.1	1
White oak	2	1	0.0	0.3	1
Northern pin oak	2	1	0.1	0.7	1
Balsam fir	1	9	0.1	0.3	1
Tamarack	1	<1	0.0	0.1	<1
White spruce	1	5	0.2	0.6	1
Sugar maple	1	9	0.0	0.1	<1
Mountain maple	1	7	0.0	0.1	<1
Total	39	1,208	20.1	87.9	100

Table 5.—*Species composition and vegetative characteristics of the jack pine forest type in sampling zone 1*

Species	Plots	Density	Basal area	Biomass	Importance value
	Number	*Stems ha^{-1}*	*m^{2}ha^{-1}*	*T ha^{-1}*	*Percent*
Jack pine	8	641	18.0	78.9	52
Quaking aspen	5	362	2.8	12.5	20
Bur oak	3	69	0.2	0.6	6
Red pine	3	12	1.3	7.1	7
Paper birch	2	12	0.4	2.8	4
Bigtooth aspen	1	38	0.2	1.1	2
White pine	1	<1	0.1	0.4	1
Balsam fir	1	46	0.5	1.5	4
Tamarack	1	1	0.1	0.4	2
White spruce	1	27	0.8	3.1	3
Total	8	1,208	24.4	108.4	100

Table 6.—*Species composition and vegetative characteristics of the jack pine forest type in sampling zone 2*

Species	Plots	Density	Basal area	Biomass	Importance value
	Number	*Stems ha^{-1}*	*m^2ha^{-1}*	*T ha^{-1}*	*Percent*
Jack pine	7	871	15.1	64.8	48
Quaking aspen	5	201	3.1	12.8	15
Bur oak	3	182	0.9	3.1	9
Red pine	1	73	0.5	2.3	4
Northern red oak	4	127	1.6	9.3	11
Paper birch	2	90	1.1	5.3	6
Bigtooth aspen	1	28	0.9	4.0	3
Sugar maple	1	43	0.1	0.7	3
Mountain maple	1	35	0.1	0.2	2
Total	7	1,650	23.4	102.5	100

Table 7.—*Species composition and vegetative characteristics of the jack pine forest type in sampling zone 3*

Species	Plots	Density	Basal area	Biomass	Importance value
	Number	*Stems ha^{-1}*	*m^2ha^{-1}*	*T ha^{-1}*	*Percent*
Jack pine	8	632	13.8	56.2	61
Quaking aspen	1	207	1.1	4.2	10
Bur oak	4	224	0.9	3.5	16
Northern red oak	3	64	0.7	3.7	10
Northern pin oak	1	2	0.2	2.0	3
Total	8	1,129	16.7	69.6	100

Table 8.—*Species composition and vegetative characteristics of the jack pine forest type in sampling zone 4*

Species	**Plots**	**Density**	**Basal area**	**Biomass**	**Importance value**
	Number	*Stems ha^{-1}*	*m^2ha^{-1}*	*T ha^{-1}*	*Percent*
Jack pine	8	780	12.2	51.0	59
Quaking aspen	2	68	0.4	1.8	5
Bur oak	2	49	0.4	2.3	5
Red pine	2	38	1.3	5.6	7
Northern red oak	1	31	<.1	<.1	2
Paper birch	1	2	0.1	0.7	2
Black oak	3	84	0.9	6.4	10
Bigtooth aspen	1	3	0.2	1.2	2
White pine	1	4	0.1	0.3	2
White oak	2	4	0.2	1.7	4
Northern pin oak	1	3	0.2	1.2	2
Total	8	1,066	16.0	72.2	100

Table 9.—*Species composition and vegetative characteristics of the jack pine forest type in sampling zone 5*

Species	Plots	Density	Basal area	Biomass	Importance value
	Number	*Stems ha^{-1}*	*m^2ha^{-1}*	*T ha^{-1}*	*Percent*
Jack pine	8	802	16.2	68.6	67
Quaking aspen	2	17	0.3	1.3	5
Red pine	4	52	1.1	4.4	10
Northern red oak	1	17	0.5	3.5	4
Paper birch	1	7	0.1	0.5	2
Black oak	1	41	1.1	6.5	6
Black spruce	2	51	0.4	1.5	6
Total	8	987	19.7	86.3	100

Table 10.—*Red pine forest type species composition and vegetative characteristics, all sampling zones*

Species	Plots	Density	Basal area	Biomass	Importance value
	Number	*Stems ha^{-1}*	*m^{2}ha^{-1}*	*T ha^{-1}*	*Percent*
Red pine	27	1066	21.8	86.7	64
Quaking aspen	8	76	0.8	3.7	6
Jack pine	7	70	1.2	4.5	6
Red maple	3	9	0.2	1.3	2
Sugar maple	3	20	0.2	1.4	2
Bigtooth aspen	3	21	0.2	0.7	2
Black cherry	3	11	0.1	0.5	2
Northern pin oak	3	18	0.1	0.9	2
White pine	2	22	0.6	1.5	2
Scotch pine	2	41	0.9	2.1	2
White ash	2	<1	0.1	1.4	1
White spruce	1	19	0.6	2.5	2
Paper birch	1	2	0.1	0.7	1
Balsam poplar	1	4	0.1	0.2	1
Pin cherry	1	15	<.1	<.1	1
Bur oak	1	8	<.1	<.1	1
Northern red oak	1	4	0.1	0.7	1
American elm	1	14	0.2	0.8	1
Unidentified	1	2	0.1	0.6	1
Total	27	1,422	27.4	110.2	100

Table 11.—*Species composition and vegetative characteristics of the red pine forest type in sampling zone 2*

Species	Plots	Density	Basal area	Biomass	Importance value
	Number	*Stems ha⁻¹*	*m²ha⁻¹*	*T ha⁻¹*	*Percent*
Red pine	4	1,198	21.8	88.6	57
Quaking aspen	2	103	1.6	7.8	9
Bigtooth aspen	1	73	0.2	0.9	4
Scotch pine	2	164	3.4	8.3	10
White spruce	1	76	2.4	9.8	6
Paper birch	1	10	0.4	2.9	3
Pin cherry	1	62	0.0	<.1	4
Northern red oak	1	15	0.4	2.6	4
Unidentified	1	9	0.4	2.6	3
Total	4	1,710	30.6	123.5	100

Table 12.—*Species compostion and vegetative characteristics of the red pine forest type in sampling zone 3*

Species	Plots	Density	Basal area	Biomass	Importance value
	Number	*Stems ha^{-1}*	*m^2ha^{-1}*	*T ha^{-1}*	*Percent*
Red pine	8	1,389	24.9	94.5	75
Quaking aspen	2	36	0.1	0.5	5
Jack pine	3	71	1.0	3.7	9
Black cherry	1	31	0.1	0.1	3
Northern pin oak	2	68	0.2	0.7	5
Bur oak	1	31	<.1	<.1	3
Total	8	1,626	26.3	99.5	100

Table 13.—*Species composition and vegetative characteristics of the red pine forest type in sampling zone 4*

Species	Plots	Density	Basal area	Biomass	Importance value
	Number	*Stems ha⁻¹*	*m²ha⁻¹*	*T ha⁻¹*	*Percent*
Red pine	8	873	20.9	85.1	72
Quaking aspen	1	8	0.4	2.3	3
Jack pine	1	54	1.0	3.7	5
Sugar maple	1	75	0.5	2.5	5
Northern pin oak	1	3	0.3	2.8	3
White pine	1	22	0.8	2.0	4
White ash	1	1	0.1	0.8	3
American elm	1	54	0.6	3.2	5
Total	8	1,090	24.6	102.4	100

Table 14.—*Species composition and vegetative characteristics of the red pine forest type in sampling zone 5*

Species	Plots	Density	Basal area	Biomass	Importance value
	Number	*Stems ha⁻¹*	*m²ha⁻¹*	*T ha⁻¹*	*Percent*
Red pine	7	806	19.8	78.8	54
Quaking aspen	3	158	1.2	4.1	9
Jack pine	3	156	2.6	10.5	11
Red maple	3	36	0.9	5.2	7
Sugar maple	2	5	0.4	3.1	4
Bigtooth aspen	2	10	0.4	1.8	4
Black cherry	2	13	0.5	1.8	3
White pine	1	65	1.6	3.9	3
White ash	1	1	0.4	4.6	3
Balsam poplar	1	17	0.2	0.8	2
Total	7	1,267	28.0	114.6	100

Table 15.—*Balsam fir forest type species composition and vegetative characteristics*

Species	Plots	Density	Basal area	Biomass	Importance value
	Number	*Stems ha⁻¹*	*m²ha⁻¹*	*T ha⁻¹*	*Percent*
Balsam fir	24	644	10.8	34.9	31
Paper birch	20	196	4.0	25.4	19
White spruce	15	45	0.9	4.1	5
Northern white-cedar	13	96	2.1	4.9	6
Quaking aspen	13	58	2.4	12.3	8
Red maple	9	92	0.7	4.2	6
Black spruce	6	71	0.8	3.1	4
Yellow birch	6	12	0.3	2.0	2
Balsam poplar	6	11	0.4	1.5	2
White pine	5	10	0.6	1.9	2
Red pine	4	21	1.8	10.3	5
Jack pine	3	2	0.2	0.9	1
Tamarack	2	11	0.3	1.2	1
Sugar maple	2	13	0.1	0.5	1
Mountain maple	2	34	0.2	0.9	1
Black ash	2	2	0.1	0.2	1
Eastern hophornbeam	1	1	<.1	0.2	1
Bigtooth aspen	1	1	<.1	0.1	1
Northern red oak	1	4	0.2	1.1	2
American elm	1	19	0.1	0.7	1
Unidentified	1	16	<.1	0.1	<1
Total	24	1,359	26.0	110.5	100

Table 16.—*Species composition and vegetative characteristics of the balsam fir forest type in sampling zone 1*

Species	Plots	Density	Basal area	Biomass	Importance value
	Number	*Stems ha⁻¹*	*m²ha⁻¹*	*T ha⁻¹*	*Percent*
Balsam fir	1	180	7.7	28.0	23
Paper birch	1	459	9.3	59.6	44
Red maple	1	26	0.9	5.4	9
Red pine	1	15	4.3	29.3	15
Northern red oak	1	21	0.9	5.7	9
Total	1	701	23.1	128.0	100

Table 17.—*Species composition and vegetative characteristics of the balsam fir forest type in sampling zone two*

Species	Plots	Density	Basal area	Biomass	Importance value
	Number	*Stems ha^{-1}*	*m^{2}ha^{-1}*	*T ha^{-1}*	*Percent*
Balsam fir	4	660	11.2	36.5	32
Paper birch	3	70	2.4	15.8	10
White spruce	2	122	2.0	8.3	8
Northern white-cedar	2	26	1.5	3.5	5
Quaking aspen	2	54	1.9	9.4	7
Black spruce	2	298	2.5	9.4	12
White pine	2	24	1.1	3.0	4
Red pine	2	77	3.4	16.0	9
Jack pine	3	11	0.9	4.4	6
Tamarack	2	53	1.7	5.9	7
Total	4	1,395	28.6	112.2	100

Table 18.—*Species composition and vegetative characteristics of the balsam fir forest type in sampling zone 3*

Species	Plots	Density	Basal area	Biomass	Importance value
	Number	*Stems ha^{-1}*	*m^{2}ha^{-1}*	*T ha^{-1}*	*Percent*
Balsam fir	6	1,024	14.2	44.9	41
Paper birch	6	38	2.2	17.0	12
White spruce	4	67	1.2	5.4	7
Northern white-cedar	4	35	2.3	5.2	6
Quaking aspen	2	49	2.3	12.1	7
Red maple	1	132	0.5	3.2	5
Black spruce	2	14	0.9	3.9	4
Yellow birch	1	2	0.1	1.0	2
White pine	2	6	0.6	1.9	3
Red pine	1	13	1.2	6.1	3
Sugar maple	1	59	0.4	2.0	3
Mountain maple	1	123	0.5	2.1	4
Black ash	1	5	0.1	<.1	1
Unidentified	1	82	0.2	<.1	2
Total	6	1,649	26.7	104.8	100

Table 19.—*Species composition and vegetative characteristics of the balsam fir forest type in sampling zone 4*

Species	Plots	Density	Basal area	Biomass	Importance value
	Number	*Stems ha⁻¹*	*m²ha⁻¹*	*T ha⁻¹*	*Percent*
Balsam fir	8	614	9.7	31.2	30
Paper birch	5	123	1.7	9.7	10
White spruce	6	19	0.8	3.5	6
Northern white-cedar	4	64	2.1	4.9	6
Quaking aspen	6	92	3.6	17.9	12
Red maple	7	302	2.2	12.4	17
Black spruce	2	43	0.6	2.3	3
Yellow birch	3	7	0.9	7.2	5
Balsam poplar	3	14	0.5	2.2	3
Sugar maple	1	6	0.1	0.6	1
Black ash	1	6	0.2	0.7	2
Bigtooth aspen	1	3	0.1	0.5	1
American elm	1	95	0.7	3.6	4
Total	8	1,388	23.2	96.7	100

Table 20.—*Species composition and vegetative characteristics of the balsam fir forest type in sampling zone 5*

Species	Plots	Density	Basal area	Biomass	Importance value
	Number	*Stems ha⁻¹*	*m²ha⁻¹*	*T ha⁻¹*	*Percent*
Balsam fir	5	755	11.1	34.0	31
Paper birch	5	288	4.4	24.8	20
White spruce	3	15	0.7	3.1	5
Northern white-cedar	3	337	4.6	10.9	14
Quaking aspen	3	94	4.3	21.9	12
Yellow birch	2	52	0.3	1.8	4
Balsam poplar	3	40	1.4	5.4	6
White pine	1	20	1.6	4.7	3
Mountain maple	1	49	0.5	2.4	3
Eastern hophornbeam	1	5	0.2	1.2	2
Total	5	1,655	29.1	110.2	100

Table 21.—*Sugar maple forest type species composition and vegetative characteristics*

Species	Plots	Density	Basal area	Biomass	Importance value
	Number	*Stems ha^{-1}*	*m^{2}ha^{-1}*	*T ha^{-1}*	*Percent*
Sugar maple	40	822	11.2	66.3	38
American basswood	21	95	2.7	12.3	8
Red maple	19	74	1.6	10.0	7
Quaking aspen	18	39	1.3	7.2	5
Northern red oak	16	58	1.8	14.2	6
Paper birch	14	24	1.0	7.2	4
Eastern hophornbeam	13	159	0.7	3.3	5
Balsam fir	11	81	0.6	1.8	4
Yellow birch	8	20	0.6	3.7	2
American elm	8	26	0.8	6.0	3
White ash	7	24	0.7	4.3	3
Black ash	7	36	0.4	1.1	2
Bigtooth aspen	7	12	0.6	3.5	2
Bur oak	6	9	0.4	2.5	2
White spruce	5	8	0.1	0.4	1
Northern white-cedar	5	3	0.1	0.3	1
Hemlock	5	3	0.2	0.9	2
Green ash	5	12	0.2	0.7	1
Black cherry	5	16	0.5	2.0	2
Beech	4	4	0.2	1.6	1
Unidentified	4	53	0.1	0.7	1
White pine	2	<1	<.1	0.1	<1
Bitternut hickory	2	18	0.1	0.2	<1
Tamarack	1	<1	<.1	0.1	<1
Mountain maple	1	12	<.1	<.1	<1
Balsam poplar	1	<1	<.1	0.1	<1
Total	40	1,608	25.9	150.5	100

Table 22.—*Species composition and vegetative characteristics of the sugar maple forest type in sampling zone 1*

Species	Plots	Density	Basal area	Biomass	Importance value
	Number	*Stems ha⁻¹*	*m²ha⁻¹*	*T ha⁻¹*	*Percent*
Sugar maple	8	664	8.5	48.8	26
American basswood	7	232	5.7	25.4	13
Quaking aspen	5	66	3.0	15.8	7
Northern red oak	4	14	1.4	12.9	5
Paper birch	3	12	0.5	3.8	3
Eastern hophornbeam	5	472	0.9	3.8	11
Balsam fir	1	31	0.0	<.1	1
American elm	5	77	2.4	16.1	7
White ash	1	7	0.2	1.2	2
Black ash	4	44	0.5	1.5	3
Bigtooth aspen	2	39	2.0	12.4	4
Bur oak	5	41	1.7	12.0	6
Green ash	4	52	0.7	2.8	4
Black cherry	1	8	0.2	.8	1
Unidentified	4	265	0.7	3.4	7
Total	8	2,024	28.4	160.7	100

Table 23.—*Species composition and vegetative characteristics of the sugar maple forest type in sampling zone 2*

Species	Plots	Density	Basal area	Biomass	Importance value
	Number	*Stems ha⁻¹*	*m²ha⁻¹*	*T ha⁻¹*	*Percent*
Sugar maple	8	732	9.5	59.3	35
American basswood	7	170	5.0	23.2	14
Red maple	2	5	0.3	2.4	2
Quaking aspen	3	11	0.6	3.5	3
Northern red oak	4	76	2.5	19.1	8
Paper birch	6	72	2.8	18.7	10
Eastern hophornbeam	3	46	0.4	2.1	3
Balsam fir	3	33	0.3	0.9	3
Yellow birch	3	20	1.4	10.7	5
American elm	1	6	1.0	10.6	3
Black ash	1	129	1.1	3.0	4
Bigtooth aspen	1	1	0.1	0.9	1
Bur oak	1	5	0.1	0.6	1
Northern white-cedar	3	8	0.3	0.7	2
Green ash	1	8	0.2	0.9	1
Bitternut hickory	1	62	0.2	0.7	2
Mountain maple	1	62	0.1	0.2	2
Balsam poplar	1	1	0.1	0.5	1
Total	8	1,447	26.0	158.0	100

Table 24.—*Species composition and vegetative characteristics of the sugar maple forest type in sampling zone 3*

Species	Plots	Density	Basal area	Biomass	Importance value
	Number	*Stems ha⁻¹*	*m²ha⁻¹*	*T ha⁻¹*	*Percent*
Sugar maple	8	979	10.4	58.5	36
American basswood	2	58	1.5	6.8	4
Red maple	5	79	1.3	7.6	6
Quaking aspen	4	43	1.0	5.6	5
Northern red oak	5	178	3.6	25.0	12
Paper birch	5	36	1.8	13.7	7
Eastern hophornbeam	2	191	0.9	4.3	6
Balsam fir	3	137	1.6	5.2	6
Yellow birch	2	43	0.4	2.0	2
American elm	2	47	0.6	3.3	3
White ash	2	65	0.9	5.0	4
Black ash	1	3	0.2	0.8	1
Bigtooth aspen	1	6	0.2	1.2	2
White spruce	3	32	0.2	1.3	3
White pine	2	1	0.2	0.7	2
Bitternut hickory	1	31	0.1	0.1	1
Total	8	1,929	24.9	141.1	100

Table 25.—*Species composition and vegetative characteristics of the sugar maple forest type in sampling zone 4*

Species	Plots	Density	Basal area	Biomass	Importance value
	Number	*Stems ha⁻¹*	*m²ha⁻¹*	*T ha⁻¹*	*Percent*
Sugar maple	8	982	14.1	82.3	47
Red maple	7	157	3.1	18.2	13
Quaking aspen	4	56	1.4	7.8	6
Eastern hophornbeam	1	4	0.1	0.6	1
Balsam fir	3	169	0.8	2.1	6
Yellow birch	3	38	1.0	5.7	5
White ash	2	8	0.4	2.8	3
Black ash	1	1	0.1	0.4	1
Bigtooth aspen	1	1	0.1	0.7	1
White spruce	2	7	0.1	0.9	2
Northern white-cedar	2	5	0.3	0.7	1
Hemlock	3	13	0.8	3.2	3
Black cherry	2	7	0.3	1.2	2
Tamarack	1	2	0.1	0.4	1
Northern red oak	2	17	1.3	10.9	5
American basswood	2	9	0.8	4.0	3
Total	8	1,476	24.8	141.9	100

Table 26.—*Species composition and vegetative characteristics of the sugar maple forest type in sampling zone 5*

Species	Plots	Density	Basal area	Biomass	Importance value
	Number	*Stems* ha^{-1}	$m^2 ha^{-1}$	*T* ha^{-1}	*Percent*
Sugar maple	8	752	13.8	82.5	48
American basswood	3	5	0.4	2.4	4
Red maple	5	127	3.3	21.7	13
Quaking aspen	2	18	0.6	3.2	3
Northern red oak	1	6	0.3	3.0	2
Eastern hophornbeam	2	84	1.0	5.6	6
Balsam fir	1	35	0.2	0.8	2
White ash	2	41	1.8	12.2	6
Bigtooth aspen	2	12	0.4	2.3	3
Hemlock	2	4	0.3	1.5	5
Black cherry	2	63	2.2	8.1	2
Beech	4	17	1.0	8.0	6
Total	8	1,164	25.3	151.3	100

Table 27.—*Aspen forest type species composition and vegetative characteristics, all sampling zones*

Species	Plots	Density	Basal area	Biomass	Importance value
	Number	*Stems ha*$^{-1}$	*m*^{2}*ha*$^{-1}$	*T ha*$^{-1}$	*Percent*
Quaking aspen	39	512	12.2	59.2	36
Paper birch	21	70	1.1	6.7	7
Red maple	18	224	2.1	11.8	10
Balsam fir	13	347	2.2	6.4	11
Sugar maple	9	120	0.6	3.1	5
Balsam poplar	7	37	0.7	2.6	3
Bur oak	7	26	0.5	3.0	3
White spruce	6	44	0.5	1.8	2
Bigtooth aspen	6	40	0.9	4.6	3
Northern red oak	6	10	0.4	3.1	2
American elm	6	21	0.5	3.4	3
American basswood	5	29	0.4	1.6	2
Black ash	4	12	0.1	0.4	1
Black cherry	4	16	0.2	0.8	1
Northern white-cedar	3	12	0.2	0.6	1
Eastern hophornbeam	3	23	0.1	0.6	1
Jack pine	2	1	0.1	0.2	1
Red pine	2	3	0.1	0.6	1
Yellow birch	2	24	0.2	0.9	1
Green ash	2	24	<.1	0.1	1
Chokecherry	2	16	<.1	<.1	1
White oak	2	9	0.1	0.6	1
Black spruce	1	3	0.1	0.3	1
White pine	1	<1	<.1	0.1	1
Hemlock	1	2	0.1	0.3	1
American hornbeam	1	5	<.1	0.1	<1
Sassafras	1	8	<.1	<.1	<1
Unidentified	1	6	<.1	<.1	<1
Total	39	1,644	23.4	112.9	100

Table 28.—*Species composition and vegetative characteristics of the aspen forest type in sampling zone 1*

Species	Plots	Density	Basal area	Biomass	Importance value
	Number	*Stems ha^{-1}*	*$m^2 ha^{-1}$*	*$T\ ha^{-1}$*	*Percent*
Quaking aspen	6	655	17.9	87.5	55
Paper birch	1	4	0.1	0.9	3
Balsam fir	2	270	3.2	9.8	14
Sugar maple	1	165	0.3	1.0	7
Balsam poplar	1	4	0.1	0.5	2
Bur oak	2	46	0.4	2.5	6
White spruce	1	124	0.3	0.8	5
American elm	1	5	0.4	3.6	3
Jack pine	1	2	0.1	0.7	2
Chokecherry	1	41	<.1	0.1	3
Total	6	1,316	22.8	107.4	100

Table 29.—*Species composition and vegetative characteristics of the aspen forest type in sampling zone 2*

Species	Plots	Density	Basal area	Biomass	Importance value
	Number	*Stems ha^{-1}*	*$m^2 ha^{-1}$*	*$T\ ha^{-1}$*	*Percent*
Quaking aspen	8	541	14.7	72.3	43
Paper birch	4	124	1.5	8.9	10
Red maple	1	2	0.1	0.7	1
Balsam fir	1	36	1.2	4.1	3
Sugar maple	2	206	0.2	0.5	7
Balsam poplar	3	55	1.5	5.4	6
Bur oak	3	74	1.5	8.5	8
Northern red oak	2	18	0.5	3.5	3
American elm	1	3	0.1	0.7	2
American basswood	1	116	0.8	2.2	4
Black ash	2	34	0.2	0.8	3
Northern white-cedar	1	1	0.1	0.2	2
Eastern hophornbeam	1	62	0.4	1.6	3
Green ash	1	93	0.2	0.5	3
Unidentified	1	31	<.1	0.1	2
Total	8	1,396	23.0	110.0	100

Table 30.—*Species composition and vegetative characteristics of the aspen forest type in sampling zone 3*

Species	Plots	Density	Basal area	Biomass	Importance value
	Number	*Stems ha^{-1}*	*m^{2}ha^{-1}*	*T ha^{-1}*	*Percent*
Quaking aspen	9	622	11.3	53.6	34
Paper birch	7	143	1.9	10.6	11
Red maple	3	271	1.8	9.5	10
Balsam fir	4	780	3.9	10.5	19
Balsam poplar	1	2	0.1	0.4	1
Bur oak	1	7	0.3	2.1	2
White spruce	3	37	0.9	3.3	4
Bigtooth aspen	3	21	1.7	10.8	6
Northern red oak	1	11	0.4	2.9	2
American elm	2	9	0.3	1.9	2
American basswood	2	14	0.7	2.9	3
Black ash	1	20	0.3	0.8	2
Black cherry	1	27	0.1	0.2	1
Jack pine	1	1	0.1	0.5	1
Black spruce	1	13	0.4	1.6	2
Total	9	1,978	24.2	111.6	100

Table 31.—*Species composition and vegetative characteristics of the aspen forest type in sampling zone 4*

Species	Plots	Density	Basal area	Biomass	Importance value
	Number	*Stems ha^{-1}*	*m^{2}ha^{-1}*	*T ha^{-1}*	*Percent*
Quaking aspen	10	524	10.8	51.7	31
Paper birch	7	59	1.4	8.2	8
Red maple	9	778	5.7	31.6	29
Balsam fir	4	158	0.7	2.3	6
Sugar maple	4	111	1.4	7.9	7
Bur oak	1	5	0.3	1.8	1
White spruce	1	4	0.3	1.3	1
Bigtooth aspen	1	1	0.1	0.5	1
Northern red oak	1	5	0.1	0.5	1
American elm	1	25	0.1	0.2	1
American basswood	1	2	0.1	0.4	1
Black ash	1	5	0.2	0.5	1
Black cherry	1	25	<.1	<.1	1
Northern white-cedar	1	2	0.1	0.2	1
Eastern hophornbeam	2	52	0.3	1.3	2
Yellow birch	2	122	0.8	4.5	5
Green ash	1	25	<.1	0.1	1
Hemlock	1	8	0.3	1.4	1
American hornbeam	1	25	0.1	0.4	1
Total	10	1,966	22.8	114.8	100

Table 32.—*Species composition and vegetative characteristics of the aspen forest type in sampling zone 5*

Species	Plots	Density	Basal area	Biomass	Importance value
	Number	*Stems ha^{-1}*	*m^{2}ha^{-1}*	*T ha^{-1}*	*Percent*
Quaking aspen	6	219	6.4	31.2	19
Paper birch	2	18	0.7	5.1	4
Red maple	5	70	2.7	17.2	11
Balsam fir	2	490	1.8	5.1	14
Sugar maple	2	117	1.1	6.2	6
Balsam poplar	2	124	1.8	6.9	7
White spruce	1	53	0.9	3.6	2
Bigtooth aspen	2	177	2.6	11.8	9
Northern red oak	2	16	1.0	8.6	5
American elm	1	61	1.6	10.5	5
American basswood	1	14	0.6	2.4	2
Black cherry	2	29	1.0	3.7	4
Northern white-cedar	1	56	1.1	2.6	2
Red pine	2	16	0.7	3.2	2
Chokecherry	1	41	<.1	0.1	2
White oak	2	46	0.5	3.0	4
White pine	1	2	0.1	0.4	1
Sassafras	1	41	<.1	0.1	1
Total	6	1,590	24.6	121.7	100

Table 33.—*Common and scientific names of species used in this Resourc Bulletin (after Doman* et al. *1981)*

Common name	Scientific name
Balsam fir	*Abies balsamea*
Tamarack	*Larix laricina*
White spruce	*Picea glauca*
Black spruce	*Picea mariana*
Jack pine	*Pinus banksiana*
Red pine	*Pinus resinosa*
White pine	*Pinus strobus*
Scotch pine	*Pinus sylvestris*
Northern white-cedar	*Thuja occidentalis*
Hemlock	*Tsuga canadensis*
Red maple	*Acer rubrum*
Sugar maple	*Acer saccharum*
Mountain maple	*Acer spicatum*
Yellow birch	*Betula alleghaniensis*
Paper birch	*Betula papyrifera*
American hornbeam	*Carpinus caroliniana*
Bitternut hickory	*Carya cordiformis*
Beech	*Fagus grandifolia*
White ash	*Fraxinus americana*
Black ash	*Fraxinus nigra*
Green ash	*Fraxinus pennsylvanica*
Eastern hophornbeam	*Ostrya virginiana*
Balsam poplar	*Populus balsamifera*
Bigtooth aspen	*Populus grandidentata*
Quaking aspen	*Populus tremuloides*
Black cherry	*Prunus serotina*
Chokecherry	*Prunus virginiana*
White oak	*Quercus alba*
Northern pin oak	*Quercus ellipsoidalis*
Bur oak	*Quercus macrocarpa*
Northern red oak	*Quercus rubra*
Black oak	*Quercus velutina*
Sassafras	*Sassafras albidum*
American basswood	*Tilia americana*
American elm	*Ulmus americana*

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Ohmann, Lewis F.; Grigal, David F.; Shifley, Stephen R.; Berguson, William E.

1994. **Vegetative characteristics of five forest types across a Lake States sulfate deposition gradient.** Resour. Bull. NC-154. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 29 p.

Presents the vegetative characteristics of the five forest types that comprised the study plots established to test the hypothesis that the wet sulfate deposition gradient across the Lake States is reflected in the amount of accumulated sulfur in soil and tree tissue, which in turn is reflected in tree growth.

KEY WORDS: Acid rain, Lake States vegetation, forest vegetation description, biomass, forest type description.

Our job at the North Central Forest Experiment Station is discovering and creating new knowledge and technology in the field of natural resources and conveying this information to the people who can use it. As a new generation of forests emerges in our region, managers are confronted with two unique challenges: (1) Dealing with the great diversity in composition, quality, and ownership of the forests, and (2) Reconciling the conflicting demands of the people who use them. Helping the forest manager meet these challenges while protecting the environment is what research at North Central is all about.

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